

GROUND EFFECT AND THE HELICOPTER--A SUMMARY

R. W. PROUTY*
Hughes Helicopters, Inc.
Culver City, Calif.

Abstract

Unlike the airplane which as a general rule, flies high and fast; the helicopter finds much of its reason-for-being while flying low and slow. For this reason, the effect of ground proximity on the helicopter is not only important during terminal operations, but in many other flight regimes as well. The paper discusses the reduction in power due to ground effect in both hover and forward flight and some of the secondary effects which have been identified in each flight regime.

Hover

Power Reduction

A helicopter hovering close to the ground requires considerably less power than when it is hovering high above it. This beneficial ground effect can be used to provide significant operational advantages when the aircraft is loaded to the point where the power available for hovering is marginal. The source of this benefit may be visualized by picturing an image helicopter flying upside down at the same distance below the ground as the actual rotor is above it so that there is no velocity across the ground boundary as shown in Figure 1. The image wake is considered to be formed of a series of spiral vortex filaments generated at the blade tips and carried up by the wake of the image rotor. This concept was first used in the 1930's at Georgia Tech by Knight & Hefner¹ to calculate the upward velocity at the actual rotor "induced" by the vortex field of the image rotor. Superimposing this upward velocity on the downward velocity field calculated for a rotor out-of-ground effect produces the in-ground effect distribution. (That the presence of the ground can influence the flow conditions at the rotor can be demonstrated at the breakfast table. The characteristics of the stream of syrup leaving the lip of the pitcher will depend upon the proximity of the pancake as shown in Figure 2.) The local effect of the ground induced velocity at the blade element is shown in Figure 3. It may be seen that when the rotor is operating in ground effect, the local velocity approaching the blade element has less downward slope than when operating out of ground effect. Most of the power required to hover is due to the rearward tilt of the lift vector which is perpendicular to the local velocity vector. The smaller the

slope, the smaller is the rearward tilt or "induced drag." The "profile drag" due to skin friction accounts for approximately a third of the power and is relatively unaffected by ground proximity. The key to the ground effect calculation is how much the induced velocity at the rotor disc is reduced compared to what it would be out of ground effect.

Testing

Knight and Hefner were not satisfied to leave their study in analytical form; they also tested several rotor models using a ground plane in the Georgia Tech wind tunnel. One of these is shown in Figure 4. Similar model tests were also done by Bellinger in the 1970's at the United Aircraft Corporation Research Laboratories.² The results of these model tests are usually presented as the ratio of the thrust that can be generated in ground effect to the thrust out of ground effect at constant power plotted against the ratio of rotor height above the ground to rotor diameter as shown in Figure 5.

Besides tests of models, it is possible to measure ground effect in hover during flight test of an actual helicopter. The first tests of this type relied on the pilot to hold a precise hover height while reading the power from his engine instruments. Changing the height then produced another test point and showed the change in power at a given thrust. Repeating the procedure at several gross weights gave enough data to cross plot and determine the effect of ground proximity on the trust capability at constant power. An improvement in the test procedure has been the development of "tethered hover" as shown in Figure 6 where a cable between the helicopter and a winch on the ground is used to precisely fix the height. The tension in the cable is measured with a load cell so that several values of rotor thrust corresponding to gross weight plus cable tension can be quickly obtained at each height. The U.S. Army Aviation Engineering Flight Activity (USAAEFA) at Edwards Air Force Base in California has taken the lead in this type of data gathering.

So far, all tests whether of models or of actual helicopters have been done over solid surfaces. Many pilots report that if the surface is water or tall grass, the ground effect is diminished. At this time, there is no test data with which to either support or refute this claim, but it would make a good student project.

*Staff Engineer, Flying Qualities